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FREQUENCY OF WINDS BETWEEN GIVEN VELOCITIES

By C. E. P. BROOKS, I.S.O., D.Sc.

Windmills for generating electricity only operate between certain limits of wind speed. Below the lower limit the power generated is insufficient, above the upper limit the apparatus has to be put out of action to avoid damage. The frequency of winds within the effective range is therefore of great economic importance. Generators could well be mounted on towers about 100–200 ft. high, so that the range required is at this height.

The frequency distribution of winds in a normal circular distribution has been calculated by Brooks, Durst and Carruthers* in terms of "constancy" and resultant wind velocity. Constancy is defined as

$$100.\frac{\text{vector mean velocity}}{\text{scalar mean velocity}};$$

the tables can therefore be used for calculating the frequency distribution of winds of different velocities if we know the mean wind speed and the constancy In the British Isles the constancy is about 40 per cent. near the surface and 50 per cent. in the free air.

An average effective range for a windmill is between 12·5 and 31·5 m.p.h. In Fig. 1 the smooth curve shows the calculated percentage frequencies of winds within this range (ordinate), for different mean wind speeds (abscissa), for a constancy of 40 per cent.

To see how this curve agreed with actual observations, mean wind speeds and frequencies between 12·5 and 31·5 m.p.h. were calculated by Dr. J. Glasspoole for 16 anemometer stations. The results are shown in Table I and by the small crosses on the left in Fig. 1.

The stations represent a great variety of exposures and some of them cover only a few years. Nevertheless, with the single exception of St. Ann's Head, the observed and calculated values agree quite well. The discrepancy at St. Ann's Head can be attributed to the exposure, which is very open on the

*BROOKS, C. E. P., DURST, C. S., and CARRUTHERS, N. ; Upper winds over the world. Part 1, The frequency distribution of winds at a point in the free air. *Quart. J. R. met. Soc., London*, 72, 1946, p. 55.

TABLE I—OBSERVED AND CALCULATED FREQUENCIES OF WINDS, 12·5–31·5 M.P.H.

Station	Mean velocity	Frequency, 12·5–31·5 m.p.h.	
		Observed	Calculated
	m.p.h.	%	%
Bell Rock	18·0	59	62
Lerwick	17·5	58	60
St. Ann's Head	17·5	52	60
Scilly	17·2	57	58
Tiree	15·9	55	56
Kirkwall	14·6	53	53
Calshot	12·9	46	46
Cardington	12·5	35	44
Lympne	12·4	39	43
Gorleston	11·8	37	41
Croydon	11·0	31	35
Mildenhall	10·7	35	33
Birmingham	10·4	37	32
Cranwell	10·3	34	32
Aldergrove	10·0	29	30
Sealand	9·7	28	29

side of the strongest winds but sheltered on the side of the weaker winds, so that the frequency of the winds in the middle range tends to be too low. The reason why the other crosses with mean wind speeds of 17 m.p.h. or more lie slightly below the curve is probably that they are annual means ; the monthly mean

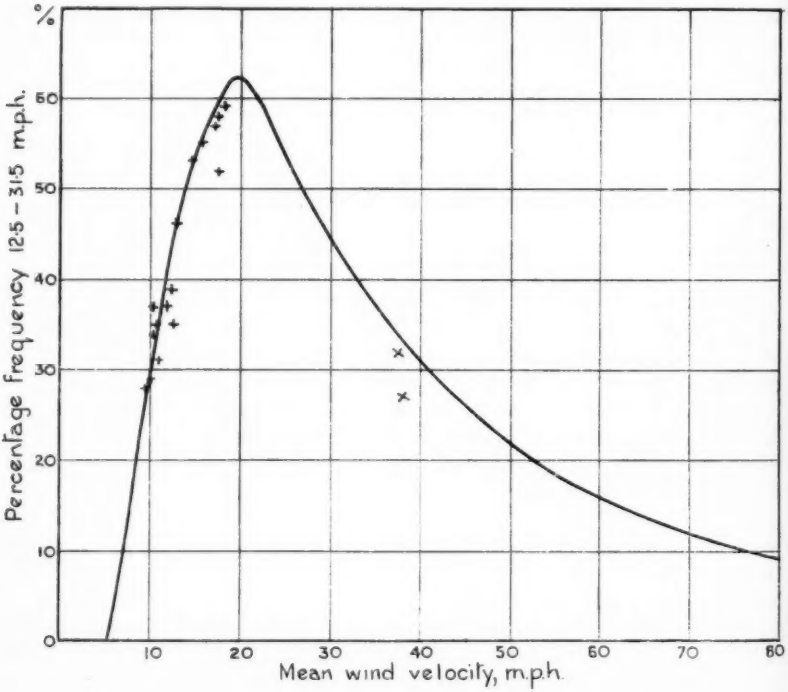

FIG. 1—DURATION OF WINDS BETWEEN 12·5 AND 31·5 M.P.H.

velocities are spread over a considerable range over which the curve is convex upwards.

These data, obtained in general at the normal anemometer height of 33 ft. above the ground, suffice to establish the ascending arm of the theoretical curve. Bell Rock with its effective height of 126 ft. has the highest mean wind velocity of any anemometer station in the British Isles and to check the descending arm of the curve it was necessary to use upper air data. For this purpose the observed frequencies at Larkhill, December-February 1939–40 to 1944–45 at the 600-mb. level and at Lerwick, June–August 1942–44 at the 400-mb. level, extracted from " Upper winds over the world ", were used ; these gave :

Larkhill, mean velocity 38 m.p.h., frequency, observed 27 per cent., calculated 32 per cent.

Lerwick, mean velocity 37·5 m.p.h. frequency, observed 32 per cent., calculated 33 per cent. Here again the agreement is as good as could be expected.

From Fig. 1 it appears that the greatest duration of winds between 12·5 and 31·5 m.p.h. in the British Isles is found where the mean wind is between 15 and 25 m.p.h. But the frequency distribution of winds within this range varies according to the mean wind velocity. The higher the mean velocity the greater the proportion in the upper half of the range. Fig. 2 shows the distribution of effective energy, obtained by multiplying the frequency by the cube of the wind velocity. The abscissa is the mean wind velocity as before ; the ordinate is the effective energy expressed as a percentage of the maximum possible, which would be given by a steady wind of 31·5 m.p.h. blowing all the time. The maximum energy is given by a mean wind velocity of about 23 m.p.h.

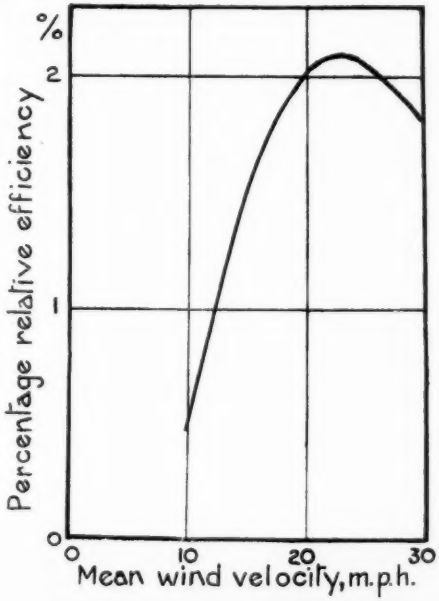

FIG. 2—RELATIVE EFFICIENCY OF WINDS

At a height of 33 ft. the highest mean velocity in the British Isles is about 17·5 m.p.h. At a height of 200 ft. the mean velocity is about 1·35 times that at 33 ft.,* so that at 200 ft. the greatest mean velocity to be expected is about 24 m.p.h., which comes near the point of greatest efficiency. In such conditions, allowing for the annual variation of mean velocity, the realisable power would be about two per cent. of the theoretical maximum.

ESTIMATION OF TEMPERATURE IN THE 700-MB. AND 500-MB. SURFACES

By J. M. CRADDOCK, M.A.

The present investigation was undertaken to provide the practical upper air analyst with a tool capable of routine use over the wide area in temperate latitudes for which upper air information is regularly available. The general nature of the results is not unexpected, and could indeed be deduced from a paper published by Mr. C. K. M. Douglas in 1930.†

A frequency table was constructed, the elements being t, the thickness of the 700–500-mb. layer, and T_7, the temperature at 700 mb., as given by each available upper air sounding on each of 12 days (one day being chosen at random from each month of the year 1947). The area covered was that of the main upper air charts at the Central Forecasting Office, and the data were obtained from the filed tephigrams. The soundings relate to conditions of extreme heat, in the north African summer, and of extreme cold, in Russia and Greenland in winter, as well as to maritime and continental air masses of the types usually affecting the British Isles. The filed tephigrams included a few soundings which had been rejected on grounds of instrumental or transmission errors ; these were ignored, and the rest, 1,071 in all, are grouped in a frequency table (Table I), the grouping interval being 50 ft. for the thickness of the 700–500-mb. layer and 2°F. for the 700-mb. temperature.

A second frequency table was made, the elements being t, the 700–500-mb. thickness, and T_5 the temperature at 500 mb. plotted for all stations on the main upper air charts at the Central Forecasting Office on each of 12 days. As before, the days chosen were intended to include the full range of temperature to be expected during the year while minimising the likelihood that any one type of pressure field was unduly prevalent, but subject to this the charts taken were those which came readily to hand. The days examined were the 6th and 7th of the following months : January 1946, January 1947, and February to May 1948. A few observations were rejected which had been disallowed in the analysis, and where there was some additional reason to doubt their correctness. Neglecting these, fewer than 20 in all, 1,286 observations remained, and were grouped in a frequency table (Table II), the grouping intervals being the same as for the first table.

From Table I the correlation between T_7 in degrees Fahrenheit and t in feet is found to be ·974, the regression of 700-mb. temperature on thickness is

$$T_7 = \cdot 0537t - 429, \qquad \ldots \quad (1)$$

the standard deviation of the coefficient of t is ·00048, and the standard deviation of T_7 for given t is 3·28°F.

TABLE I—FREQUENCY OF TEMPERATURES AT 700 MB. FOR DIFFERENT 700–500-MB. THICKNESSES

*CARRUTHERS, N. ; Variations in wind velocity near the ground. *Quart. J. R. met. Soc., London*, **69**, 1943, p. 289.

†DOUGLAS, C. K. M. ; On the relation between temperature and pressure in the troposphere. *Mem. R. met. Soc., London*, **3**, No. 29, 1930, p. 159.

TABLE I.—FREQUENCY OF TEMPERATURES AT 700 MB. FOR DIFFERENT 700–500-MB. THICKNESSES

Thickness of 700–500-mb. layer in feet

°F.	7,510– 7,550	7,560– 7,600	7,610– 7,650	7,660– 7,700	7,710– 7,750	7,760– 7,800	7,810– 7,850	7,860– 7,900	7,910– 7,950	7,960– 8,000	8,010– 8,050	8,060– 8,100	8,110– 8,150	8,160– 8,200	8,210– 8,250	8,260– 8,300	8,310– 8,350	8,360– 8,400	8,410– 8,450	8,460– 8,500	8,510– 8,550	8,560– 8,600	8,610– 8,650	8,660– 8,700	8,710– 8,750	8,760– 8,800	8,810– 8,850	8,860– 8,900	8,910– 8,950	8,960– 9,000
60																														
59, 58																														
57, 56																												2	1	
55, 54																												1		
53, 52																											3	2	1	
51, 50																											2	4	1	
49, 48																										2	1			
47, 46																										3				
45, 44																							1	1	2	7	1			
43, 42																							8	4	3	3	1			
41, 40																							14	16	11	7	1			
39, 38																						3	12	15	2					
37, 36																						9	21	16						
35, 34																					1	29	28	5	1					
33, 32																					9	18	12	2	1					
31, 30																					18	25	6							
29, 28																				1	11	24	5							
27, 26																			12	35	29	11								
25, 24																			12	15	8	3								
23, 22																			16	4	2	1								
21, 20																			10		1									
19, 18																			2											
17, 16																			3											
15, 16																			1											
13, 14																														
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−13, −12																														
−15, −14																														
−17, −16																														
−19, −18																														
−21, −20																														
−23, −22																														

TABLE II— FREQUENCY OF TEMPERATURE AT 500 MB. FOR DIFFERENT 700–500 MB. THICKNESSES

°F.	Thickness of 700–500-mb. layer in feet																					
	7,610–7,650	7,660–7,700	7,710–7,750	7,760–7,800	7,810–7,850	7,860–7,900	7,910–7,950	7,960–8,000	8,010–8,050	8,060–8,100	8,110–8,150	8,160–8,200	8,210–8,250	8,260–8,300	8,310–8,350	8,360–8,400	8,410–8,450	8,460–8,500	8,510–8,550	8,560–8,600	8,610–8,650	8,660–8,700	8,710–8,750
15, 14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1
13, 12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
11, 10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1
9, 8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	3	8	5
7, 6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	1	3	9	15	10	..
5, 4	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	4	5	30	11	3	..
3, 2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	1	6	33	15	6	..	..
1, 0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	6	32	24	15	..	..	..
−1, −2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	24	33	20	4	..	..	..
−3, −4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	7	36	38	12	..	..	..	..
−5, −6	..	..	..	..	..	..	..	..	..	..	..	..	..	3	5	26	43	12	1	..	1	..	..
−7, −8	..	..	..	..	..	..	..	..	..	..	..	2	3	6	21	47	26	10	..	..	..	..	..
−9, −10	..	..	..	..	..	..	..	..	..	2	..	2	5	12	24	17	4	1	..	..	..	..	..
−11, −12	..	..	..	..	..	..	..	..	..	..	..	4	8	18	33	7	3	..	..	..	..	..	..
−13, −14	..	..	..	..	..	..	..	..	..	..	3	4	19	25	11	1	..	..	..	..	..	..	..
−15, −16	..	..	..	..	..	..	..	..	..	1	2	16	20	16	..	3	1	1	..	..	..	..	..
−17, −16	..	..	..	..	..	..	..	..	..	..	9	24	9	2	..	1	..	..	..	..	..	..	..
−19, −18	..	..	..	..	..	..	..	..	1	3	15	11	6	..	..	..	..	..	..	..	..	..	..
−21, −20	..	..	..	..	..	..	..	3	4	2	16	11	2	1	..	..	..	..	..	..	..	..	..
−23, −22	..	..	..	..	1	..	2	12	7	13	7	1	..	..	..	..	..	..	..	..	..	..	..
−25, −24	..	..	..	1	2	8	9	17	10	13	..	..	..	..	..	..	..	..	..	..	..	..	..
−27, −26	..	..	..	..	..	2	5	9	9	21	5	..	..	..	..	..	..	..	..	..	..	..	..
−29, −28	..	..	..	1	..	2	3	4	4	6	..	..	..	..	..	..	..	..	..	..	..	..	..
−31, −30	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
−33, −32	..	..	..	..	1	2	3	4	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..
−35, −34	..	..	..	..	..	4	3	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..
−37, −36	..	..	..	3	..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
−39, −38	..	..	1	..	..	2	2	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..
−41, −40	..	1	2	1	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
−43, −42	1	..	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
−45, −44	1	1	5	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
−47, −46	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

The regression of thickness on 700-mb. temperature is given by the same table as

$$t = 17{\cdot}65T_7 + 8009, \quad .. \quad (2)$$

the standard deviation of the coefficient of T_7 as ·1262, and the standard deviation of t for given T_7 as 58·5 ft.

From Table II the correlation between T_5 in degrees Fahrenheit and t in feet is found to be ·962, the regression of 500-mb. temperature on thickness is

$$T_5 = {\cdot}0520t - 446, \quad .. \quad (3)$$

the standard deviation of the coefficient of t is ·00042, and the standard deviation of T_5 for given t is 3·17°F.

The regression of thickness on 500-mb. temperature is given by this table as

$$t = 17{\cdot}81T_5 + 8557, \quad (4)$$

the standard deviation of the coefficient of T_5 as ·1406, and the standard deviation of t for given T_5 as 68·70 ft.

Subtracting (3) from (1), we have

$$T_7 - T_5 = {\cdot}0017t + 17 \quad .. \quad (5).$$

The coefficient of t is significantly greater than zero, so that there is reason to think that the difference, $T_7 - T_5$, tends to be greater at high temperatures than at low.

Using equations (1) and (3), graphs may be drawn to give the most probable 700-mb. and 500-mb. temperatures corresponding to any given thickness, while equations (2) and (4) can be used for the reverse process. In practice, however, the differences between equations (1) and (2) and between (3) and (4), which arise through the two correlations falling short of unity, are small enough (less than 1°F. over the normal range of temperatures) to be disregarded in the interests of convenience. Accordingly a graph has been constructed (Fig. 1), based on the tephigram, which is a compromise and can be used to obtain temperatures from thicknesses or thicknesses from temperatures as the occasion may demand. The uses of this graph are described in the following

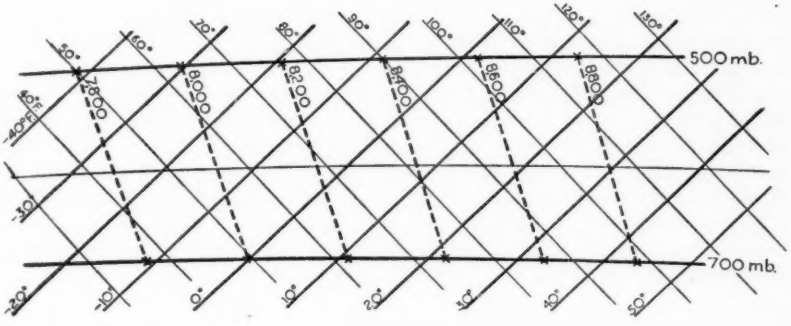

FIG. 1—RELATION BETWEEN 700–500-MB. THICKNESS AND TEMPERATURES AT 700 AND 500 MB.

Full lines give temperatures at 700 and 500 mb. in degrees Fahrenheit, pecked lines give thicknesses in feet

sections. It is especially convenient for use at a station where the technique of upper air analysis in use at the Central Forecasting Office is employed, because in that technique the isopleths of thickness of the 700–500-mb. layer are drawn as an integral part of each actual and prognostic chart, and are studied more closely and forecast more accurately than is possible for the isotherms in a particular surface.

The graph gives directly the temperature at 700 and 500 mb. corresponding to any given thickness. The temperatures corresponding to the isopleths of thickness used in the analysis at the Central Forecasting Office (those for multiples of 200 ft.) are not in general multiples of 10°F., for which isotherms are drawn, so that the isotherms usually lie between but follow the run of the thickness lines. The equivalence given by the graph (or more exactly by equations (1) and (3)) is, of course, appropriate only in places where there is no other information as to the probable lapse rate. If an air mass shows evidence of subsidence, or of deep instability, so that the lapse rate may be expected to differ from the mean, an allowance should be made by drawing the isotherms to some extent across the run of the thickness lines. Since, however, the magnitude of the standard deviations for given t of T_7 and T_5 show that fewer than 1 in 20 measured temperatures differ from the mean value by as much as 7°F., the allowance for stability or instability should be less than this unless the analyst considers that the situation in question is a wholly abnormal one. The analyst will, of course, take account of all actual reports in drawing the isotherms and estimating stability on a current chart, and, when forecasting, will consider how far the stability of any air mass as shown on the latest analysed chart is likely to change.

If the temperature at 700 or 500 mb. is accurately known, *e.g.* from the report of a meteorological reconnaissance aircraft, then the 700–500-mb. thickness will, on fewer than 1 in 20 occasions, differ from the value given by equation (2) or (4) by as much as 117 ft. or 137 ft. respectively. While such an estimate is considerably less accurate than one based on a good upper air sounding, it will serve to confirm or deny a doubtful sounding, and is quite accurate enough to be valuable in regions where no proper upper air soundings are available.

The 700–500-mb. thickness and the 500-mb. temperature are plotted on the same upper air chart at the Central Forecasting Office, and equation (3) gives a convenient check of the internal consistency of the observations. If a reported temperature does not differ from that derived from the thickness by as much as 7°F., there is no reason to suspect internal inconsistency. If the difference exceeds this figure, the incoming message should be examined with a view to eliminating transmission and clerical errors from the plotted observation. At the same time, since the frequency table shows not that larger differences are impossible but that they are rare, it is inadvisable to reject an observation which is otherwise satisfactory simply because the difference lies somewhat outside the usual range.

ERRATUM

January 1949, PAGE 21, line 5; *for* at 450 mb. in winter is 50°F. between 51°N. and 57°N. *read* at 450 mb. in winter is 50°F. between 38°N. and 67°N., and 42°F. between 51°N. and 57°N.

[*To face page* 40

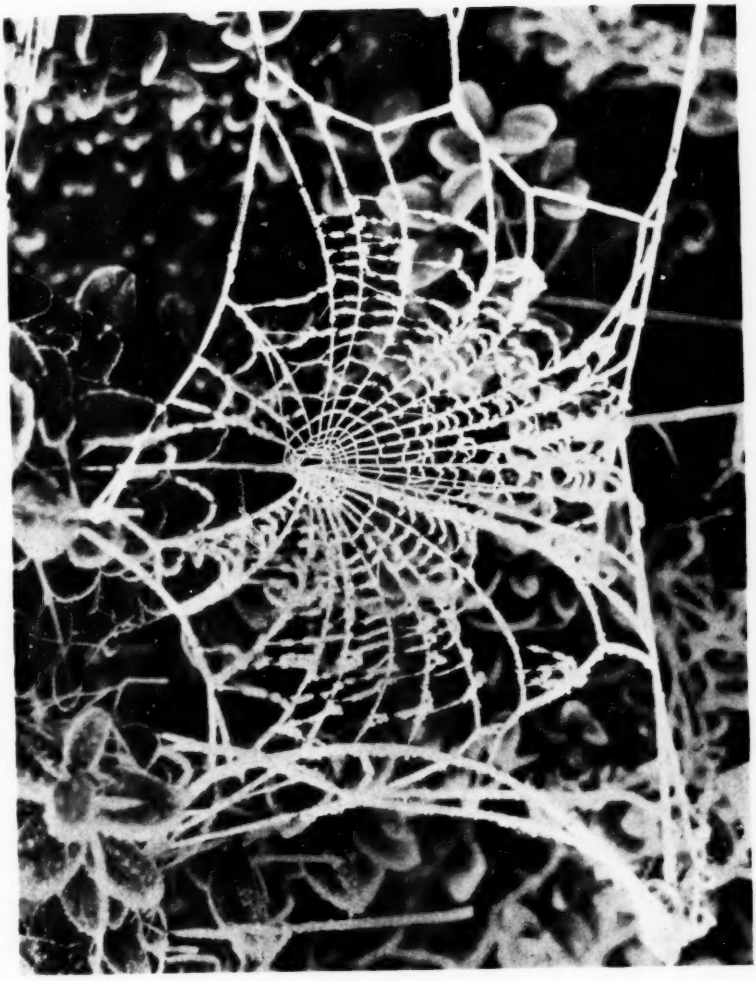

FIG. 1.—RIME ON A COBWEB AT LEEMING, NOVEMBER 23, 1948
(see p. 53)

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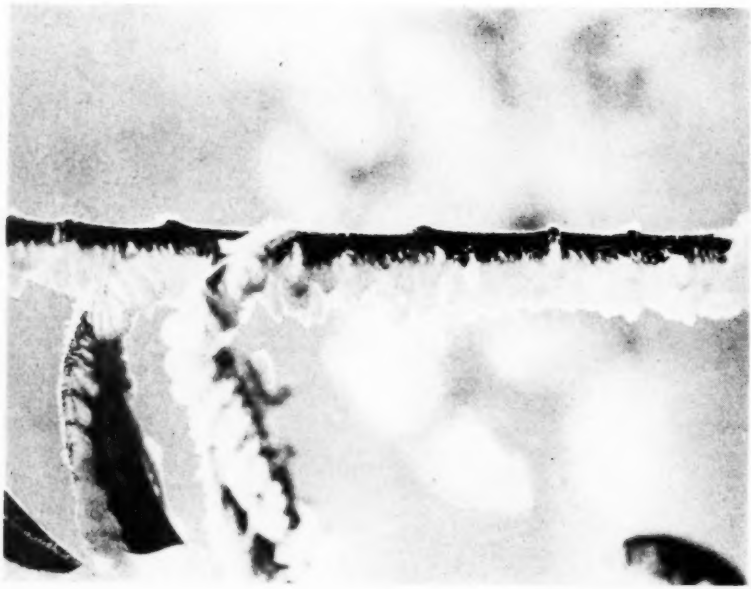


FIG. 3.—CLOSE-UP OF RIME AT LEEMING
(about three-quarters natural size)

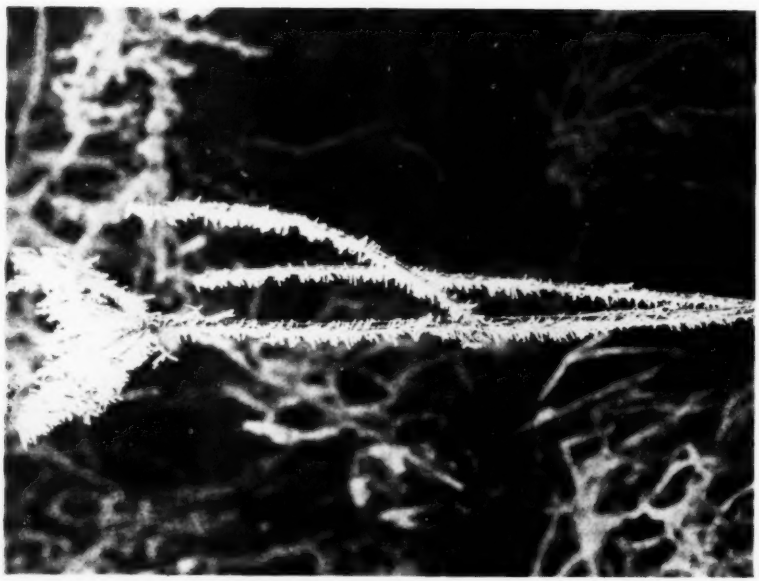


FIG. 2.—RIME ON SHRUB AT LEEMING
(see p. 51)

UNUSUAL WARM-FRONT PASSAGE AT LEUCHARS, FIFE, NOVEMBER 20, 1947

BY T. JOHNSTON

The following note gives a picture of the unusual passage of a warm front through the Leuchars area with a suggested reason for the peculiarities noted. No attempt is made to go deeply into the mechanism behind the suggestion.

On the 20th at 0600 G.M.T. a warm front lay from just south of Benbecula to Renfrew to Silloth to Croydon to north-east France. Behind it lay a wide warm sector in which the air had a long south-westerly track and was, for the season, very warm. The depression centre lay well to the west, the main centre being at 52°N. 33°W., and it was expected that by 1200 G.M.T. the front would lie from the Hebrides to Aberdeen to the western North Sea, having passed through Leuchars at about 0900 G.M.T. Local forecasts for the Leuchars area were prepared accordingly.

The weather in eastern Scotland during the preceding five days had been very cold and frost had been recorded every morning. The minimum air temperatures at Leuchars on the 18th and 19th were 22°F. and 21°F. It became cloudy on the evening of the 19th, light drizzle commenced at 2300 and the temperature rose gradually through the night to 39°F. at 0600. Thereafter the hourly sequence of local weather at the station is shown in detail in Table I.

TABLE I—WEATHER AT LEUCHARS, NOVEMBER 20, 1947

Time	Weather	Visibility	Cloud		Wind	Temperature	
						Dry bulb	Wet bulb
G.M.T.		yd.	tenths	ft.		°F.	°F.
0700	Continuous slight drizzle	3,000	10	1,200	Calm	39	39
0800	Continuous slight drizzle	1,400	10	1,000	Calm	39	39
0900	Continuous slight drizzle	1,800	10	800	SW., 2kt.	38	38
1000	Continuous slight drizzle	1,800	10	800	Calm	39	39
1100	Continuous moderate drizzle	1,500	10	800	Calm	39	39
1200	Slight drizzle and fog	600	10	600	Calm	39	39
1300	Slight drizzle and fog	600	10	600	Calm	39	39
		mi.					
1400	Cloudy	10	5 8	3,000 700	SW., 12kt.	54	54

It will be seen that there was no rise in temperature until after 1300. When this did occur, at 1330 G.M.T., the wind rose suddenly to WSW., 12 kt. and the temperature, in ten minutes, rose from 39°F. to 52°F. The visibility also rose from fog limits to 10 miles in an equally short space of time. The rapid rise in temperature is graphically shown by the reproduction of the thermograph trace, Fig. 1. It would appear that the warm front passed through Leuchars at 1330, having been preceded by conditions usually encountered when the frontal surface at ground level has been retarded by a shallow friction layer, *i.e.*, by pre-frontal fog. But the front passed through Dyce before 1300 G.M.T., as will be seen from Fig. 2, which shows the synoptic chart for Scotland at that hour. For comparative purposes Table II shows the temperatures at Leuchars, Donibristle and Dyce during the morning.

It will be seen that there was a marked rise of temperature at Donibristle between 0900 and 1000 followed by a continuing rise, and at Dyce between 1100 and 1200. It is therefore reasonable to expect that at Leuchars the

FIG. 3—CLOSE-UP OF RIME AT LEEMING (about three-quarters natural size)

FIG. 2 RIME ON SHRUB AT LEEMING (see p. 53)

TABLE II—TEMPERATURE AT DONIBRISTLE, LEUCHARS AND DYCE, NOVEMBER 20, 1947

Time	Donibristle		Leuchars		Dyce	
	Dry bulb	Dew point	Dry bulb	Dew point	Dry bulb	Dew point
G.M.T.	*degrees Fahrenheit*					
0700	44	43	39	39	41	39
0800	43	43	39	39	41	40
0900	42	42	38	38	42	40
1000	47	46	39	39	42	40
1100	51	50	39	39	42	39
1200	58	53	39	39	50	45
1300	59	54	39	39	51	47

temperature rise would have occurred somewhere between 0900 and 1100. The frontal passage everywhere had been particularly marked by temperature changes and it would appear, therefore, that the warm front did not then pass through Leuchars, on the surface, until after it had passed through Dyce, 70 miles to the north. At Arbroath no observations were taken after midday, but it is understood that the thermographic records there showed a marked and sudden rise of temperature at 1330 G.M.T. This would suggest that the phenomenon was not confined completely to Leuchars.

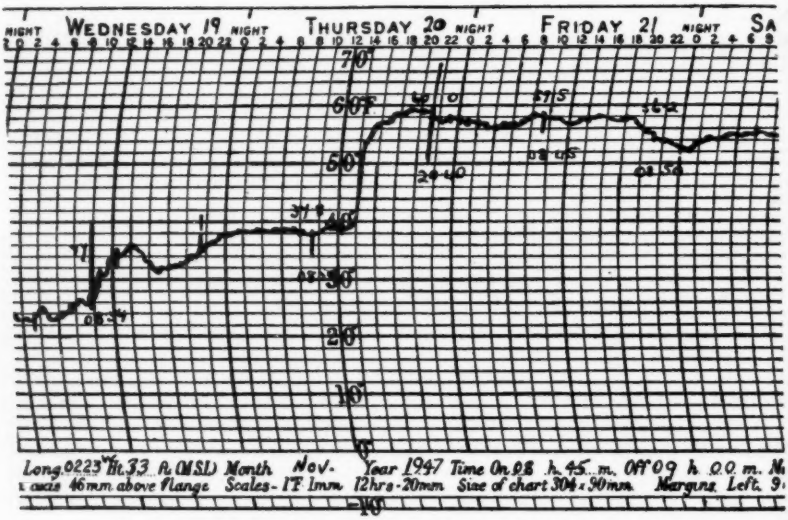

NIGHT WEDNESDAY 19 NIGHT THURSDAY 20 NIGHT FRIDAY 21 NIGHT SA
70
60
50
40
30
20
10
0
-10
Long. 0223 W. Ht. 33 ft. (MSL) Month Nov. Year 1947 Time On 08 h. 45 m. Off 09 h. 00 m.
Scales - 1F 1mm. 12hrs - 20mm. Size of chart 304 x 90mm. Margins Left.

FIG. 1—THERMOGRAM AT LEUCHARS NOVEMBER 19–21, 1947

No upper air soundings of temperature were made at Leuchars during the period under review but radio winds are available and are shown in Table III.

TABLE III—UPPER WINDS AT LEUCHARS

Height	0500		1100	
ft.	°	kt.	°	kt.
Surface	Calm		Calm	
1,000	220	24	230	24
2,000	240	25	230	30
3,000	260	33	240	45

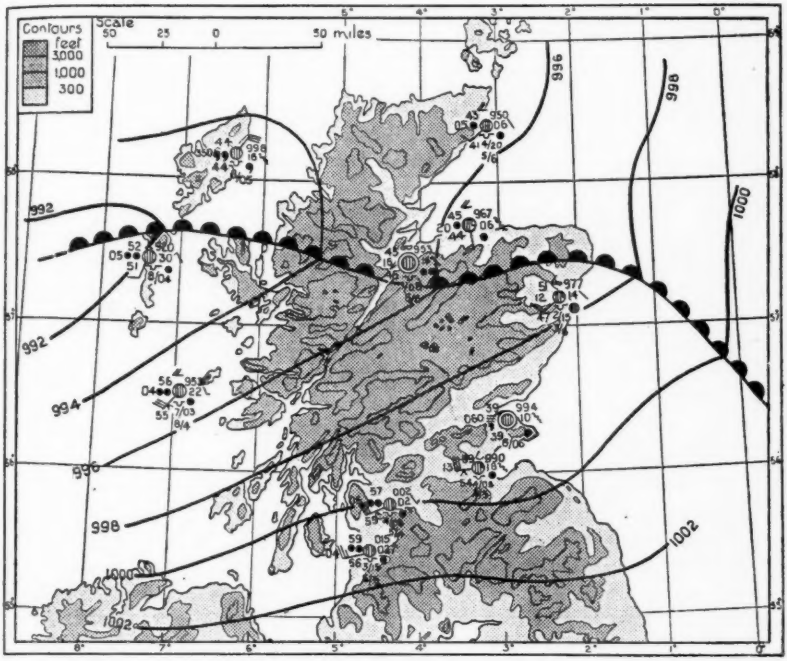


FIG. 2—SYNOPTIC CHART, 1300 G.M.T., NOVEMBER 20, 1947

Such marked variation between the wind at 1,000 ft. and the surface value in a south-westerly air stream is very unusual although there is certain shelter from the hills to the south-west of the area.

It is suggested that during the five days before the 20th a cold pool of air formed in the natural basin bounded on the north-western side by the Sidlaws and on the south-western and southern sides by the Ochils, Lomonds and higher ground of south Fife (see Fig. 3). When the warm air approaching from the south-west was lifted over this latter high ground it flowed over the top of the pool of cold air and reached the surface at a point north of Arbroath. The warm air then eventually reached the surface in the basin, not through violent and deep turbulence, which would have given a less sudden rise in temperature but through a process of gradual and comparatively shallow mixing with the top of the cold pool. Mr. C. K. M. Douglas has suggested that if the anemometer trace at Bell Rock—the only recording anemometer in the area—showed a complete calm just before the rise in the temperature it would prove mixing up to the level of the head at least. Unfortunately this suggestion could not be pursued as there is no record of the time that the temperature rose at Bell Rock, and, although it occurred sometime after the 1200 G.M.T. observation which might signify that the cold pool extended as far east as that, there is no more evidence to support this possibility.

If this theory is accepted, then, from a purist point of view, it would doubtless be correct to draw the warm front on the surface charts south of this basin in

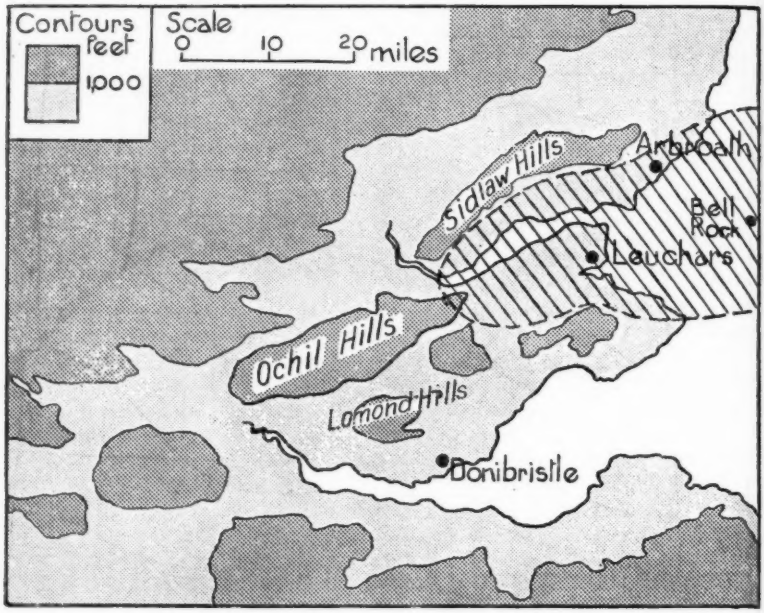


FIG. 3—SUGGESTED AREA OF COLD POOL (SHADED AREA)

the form of a wave but if this were done, for example at 1300 G.M.T. when the front would have to be through Aberdeen, the picture would be rather a peculiar one. It is not known whether such marked effects have been noticed before at this station, but it seems unlikely that they would be numerous as it must be comparatively rare to have such a marked difference in air temperatures in air masses in juxtaposition.

It might be mentioned in passing that the sudden rise of temperature had the effect of causing very rapid and severe condensation on walls and other surfaces indoors, and rivulets of water coursing down walls were not unusual.

Acknowledgements are due to Messrs. C. K. M. Douglas, D. A. Davies and T. N. S. Harrower who read the original draft of this note and made helpful suggestions.

METEOROLOGICAL RESEARCH COMMITTEE

The 56th meeting of the Committee was held on December 9, 1948.

The Committee discussed the working of the three Sub-Committees formed earlier in the year and agreed that the procedure of dealing with most of the technical papers in Sub-Committees had proved successful. It was agreed to invite some additional " outside " scientists to join the Sub-Committees.

The Committee also heard an interesting account of an attempt, which is being sponsored by the Director, Naval Meteorological Service, to compile synoptic charts of the oceans surrounding the South Pole.

OFFICIAL PUBLICATIONS

The following publications have recently been issued :—

HANDBOOK OF WEATHER MESSAGES, CODES AND SPECIFICATIONS, PARTS II AND III.

This publication, which replaces " Wireless weather messages ", consists of three parts : Part I, containing the transmission schedules of all weather broadcasts under direct British control, a list of all British synoptic reporting stations and a selection of other reporting stations ; Part II, containing full specifications of all the weather codes in use in Europe as amended since the war ; and Part III, containing instructions for coding, decoding and plotting. These three Parts, together with the amendments, contain all the new Washington codes which are now in use in Europe. An article on the Washington codes appeared in the October 1948 issue of the *Meteorological Magazine.*

Part I will be issued shortly.

PROFESSIONAL NOTES

No. 92—*Persistence of Weather*, by E. G. Bilham, B.Sc., D.I.C.

Common experience in this country shows that on most occasions the weather an hour ahead will not be materially different from what it is now. But no exact figures have been available as to the actual frequency of change, or of the material change from one hour to the next. Professional Note No. 92 gives the first results of an inquiry for two stations wide apart: Croydon and Leuchars. Broadly the figures show:—

(1) Only in 1 case out of 5 are the conditions an hour hence exactly the same as they are now.

(2) In 7 cases out of 10, the changes are slight and not of material significance from the flying point of view.

(3) In 1 case in 6 there are material changes in an hour—half the changes being improvements and half deteriorations.

(4) In 9 cases out of 10 the conditions an hour hence will be either about the same or better than they are now.

There are annual and diurnal variations—but the latter have not yet been examined. The annual variation shows, as might perhaps be expected, that winter is the season of most frequent material change.

It is hoped to provide similar summaries for other stations in further notes, and also to consider changes in a period of three hours in addition to those in a period of one hour.

No. 93. *Preliminary note on errors in forecast frontal positions on* 18*-hour prebaratics*, by C. K. M. Douglas, B.A.

The paper discusses the errors in forecasts of the positions of fronts 18 hours in advance. It was written in 1944, but an addendum gives statistics for the years 1944 to 1946 which do not differ appreciably from those for 1944 only. The average error in the forecast positions of fronts (warm, cold and occluded taken together) is 85 miles, corresponding to an error in the speed of just under 5 m.p.h. Various sources of error are discussed. The most important of these is the difficulty of making a sufficiently accurate forecast of the pressure distribution, but the ageostrophic motion of fronts is also considered.

No. 94—*Visibility and the optical properties of the atmosphere*, by Sir George Simpson, K.C.B., F.R.S.

This is a reprint of two memoranda prepared by Sir George Simpson during the war for the information of the Civil Defence Research Committee setting out the principles on which the Meteorological Office bases its observations of visibility. The physics of visibility and the results of Koschmieder's investigations are described. The theoretical relationships between the attenuation coefficient, the daylight visibility range and the distance at which lights can be seen at night are derived, and the practical difficulties of applying the theory are discussed.

A useful diagram is reproduced by which values of the visible range, the attenuation coefficient and the transmission coefficient expressed in either the mile, the kilometre or 1,000 yards as the unit of length can be converted into the corresponding values for either of the other units.

No. 95—*Calculation of night minimum temperatures*, by R. Frost, B.A.

In this note it is assumed that the temperature changes near the surface of the earth depend mainly upon the readiness with which the loss of heat from the surface is compensated by the transfer of heat downwards from the air and by the heat released by the deposition of dew.

Starting with the eddy-diffusion equation

$$\frac{\partial \chi}{\partial t} = \frac{\partial}{\partial z}\left(K_z \frac{\partial \chi}{\partial z}\right),$$

where χ is either the potential temperature or humidity mixing ratio of the air and K_z, the coefficient of eddy diffusion, is represented by a power law of the height above the surface, a solution is obtained on the assumption that, to a first approximation, the radiational flow of heat from the earth's surface and the rate of deposition of dew during the night may be taken as constant.

It is shewn that when the ground is dry the fall of temperature calculated from this solution is in close agreement with the observed fall.

ROYAL SOCIETY

At the meeting of the Royal Society on November 11, two meteorological papers were read :—

Chapman, S. and Tschu, K. K.—The lunar atmospheric tide at 27 stations widely distributed over the globe.

Goody, R. M.—The thermal equilibrium at the tropopause and the temperature of the lower stratosphere.

During the past 120 years, many investigators have attempted to show the existence of a lunar tide in the atmosphere. From data of barometric pressure at tropical stations this is comparatively simple, but with similar data for temperate regions the determination is much more difficult. It was Prof. Chapman who, in 1918 by an analysis of the pressure on quiet days selected from 63 years' data at Greenwich, first showed the existence of the lunar tide at a station in temperate latitudes. Since then he has contributed to the subject of lunar oscillations not less than twenty papers. Much of the substance of

these is given in an article in *Nature**. At the meeting now reported, many interesting slides were shown. One of the most striking was that of a harmonic dial giving the amplitude and phase of the lunar tide at Taihoku (Formosa) for the different months of the year (data for 1897 to 1932). This showed very clearly the large phase lag in January and February ; a feature which has been found to be world-wide irrespective of hemisphere. From December to February the crest of the atmospheric tide (at Taihoku) occurred between two and three hours after lunar transit whereas for the remaining nine months the lag was approximately one hour only.

The magnitude of the lunar tide over the world, for the year as a whole, was shown by isopleths of amplitude. These brought out clearly the maximum of about 80 microbars† over the Indian Ocean and the damping, due to the Rockies, along the west coast of North America.

A semi-diurnal lunar oscillation had been found also in data of temperature and wind and in the height of the E-layer of the ionosphere. The magnitude (given by the range from peak to trough) was of the order of 0·01°C. in temperature at Batavia and of 1 cm./sec. in wind at Mauritius.

Prof. Chapman's paper was largely a survey of concrete results and so there was very little discussion.

The second paper, in complete contrast, was mainly conjectural ; in fact, the observations available to verify the mechanisms described are extremely scanty.

The tropopause was defined as the transition between a lower layer of the atmosphere (the troposphere) in which transfer of heat is by convection, and an upper (the stratosphere) in which transfer of heat is by radiation. As absorption of the short-wave radiation from the sun is negligible near the tropopause, the distribution of temperature in the lower stratosphere, under stable conditions, depends mainly upon the absorption of long-wave radiation from the surface of the earth. No account was taken of the movement of air masses.

The nature of the change of temperature from troposphere to stratosphere was first considered ; it was shown that the most stable type of tropopause occurred when the lower stratosphere was isothermal.

In the latter half of the paper, arguments were put forward to explain latitudinal and seasonal variations of temperature. The latitudinal variations gave rise to much discussion. Assuming a constant lapse rate (6·5°C./Km.) of temperature in the troposphere, Mr. Goody focussed attention upon the relative amounts of heat absorbed by the stratospheric gases in different latitudes. Dobson had concluded that, in the stratosphere, temperature depended upon the proportions of ozone and water vapour, and the high temperatures over polar regions were due to high concentration of ozone. Contrary to this conclusion, Mr. Goody considered that the effect of ozone at the tropopause was a small heating effect nearly constant with latitude. Cooling was greatest with gases which thinned most rapidly with height. In latitude 70° the principal cooling agent was water vapour, in the tropics it was carbon dioxide. Variations in the absorption of heat by these gases were, to a first approximation, dependent only upon temperature and pressure at the tropopause ; warming due to water vapour decreased with increasing temperature

*CHAPMAN, S. ; Atmospheric oscillations. *Nature, London*, **159**, 1947, p. 357.
†1 microbar = 0·001 mb.

whilst that due to carbon dioxide increased with both temperature and pressure. The effect of carbon dioxide accounted for the latitudinal variation of stratosphere temperature—low over the tropics and high over the poles—being the reverse of that in the troposphere. With a constant lapse rate in the troposphere, the higher ground temperature in the tropics was associated with a higher tropopause, the temperature at which convection ceased being reached less quickly. Pressure at the tropopause therefore tended to be lower, causing absorption by carbon dioxide to be less, and, other effects being constant, this explained the occurrence of lower temperatures over the tropics than over high latitudes.

The discussion showed approval of Mr. Goody's simple and plausible explanations but disappointment concerning the many factors omitted in deriving these explanations. No account had been taken of the differing wavelengths of the radiant heat absorbed by the different gases ; and no mention had been made of advection, a probable cause of the clear-air gusts (jet streams) encountered by aircraft at tropopause level. Those taking part in the discussions were Prof. Brunt, Dr. Dobson, Dr. Scott Temple, Mr. Gold, Mr. Durst and Mr. Brewer. Dr. Dobson referred especially to the need for laboratory measurements of the absorption of gases in condition similar to those in the upper air

ROYAL ASTRONOMICAL SOCIETY

A geophysical discussion on " Wind and ocean currents " was held by the Royal Astronomical Society at 4.30 p.m. on November 26, 1948.

Dr. Doodson opened the meeting with a brief outline of the problems involved in the treatment of water movement in relation to wind. The scale of the various phenomena varies from the molecular to that of large oceanic circulations. In wave motion the occurrence of critical values must be emphasised. Jeffreys has shown that there exists a minimum wind velocity of the order of 100 cm./sec. necessary to create waves and recently a new critical velocity has been found. This velocity of some 700 cm./sec. marks the threshold between " smooth ", or laminar, flow and " rough ", or turbulent, flow and corresponds with the common experience of the occurrence of " white horses " with winds of Beaufort force 3–4 and over. Other problems on waves include their growth by absorption of energy from the wind, the transport of volume by wave motion and, as a consequence, the effect of the rotation of the earth.

Dr. Doodson then mentioned the classical work of Ekman on the theory of drift currents in an infinite ocean and briefly referred to the effect of boundaries and surface gradients made apparent in shallow seas.

Dr. Deacon, following, dealt in broad general terms with the inter-relationship between wind and current and emphasised the complexity of the problems. He showed vertical sections (due to Wüst) of the general oceanic circulation in the Atlantic Ocean, based on data from the German *Meteor* expedition and pointed out the different water-mass movements. Originally, Rennell had attributed currents to the direct effect of the wind and did not attach any importance to the specific gravity distribution. The American, M. F. Maury, on the other hand, placed great emphasis on the distribution of specific gravity and regarded the effects of the winds as local and transitory, this extreme point of view being very evident in his " Geography of the sea " and " Sailing directions ". Since that time oceanographers have tended towards one extreme

or the other and the argument exists in milder fashion even today. Dr. Deacon took pains to point out that he regarded the specific gravity distribution as playing but a minor role, capable of producing currents of a few centimetres per second but quite incapable of producing currents of the order of knots. In his view wind is the predominant generator of current.

Some interesting diagrams, taken from a recent paper by Stommel, were then shown. Stommel has sought to apply the theory of wind-driven currents to explain the intensification of the currents on the western borders of the oceans, examples being the Gulf Stream and the Kuroshio. By idealising an ocean into a rectangle with the trade winds blowing along the southern boundary and the westerlies along the northern boundary, a simple mathematical argument leads to a picture of stream-lines with both east-west and north-south symmetry for the cases of a non-rotating and a uniformly-rotating ocean. In the real ocean, however, the Coriolis force is a function of the latitude. Assuming a linear function for simplicity (this is good enough in low latitudes), Stommel demonstrates that the revised stream-line pattern is non-symmetrical in the east-west direction, showing a marked concentration of stream-lines along the western boundary.

Dr. Deacon made a brief reference to Ekman's work and then remarked on a discrepancy between the demands of the drift-current theory and the theory of wave formation. The drift-current theory requires much higher values of the eddy viscosity than can be reconciled with the theory of the formation and dissipation of surface waves. Some interesting experiments by Woodcock on convection cells in the ocean were then described. These cells show an asymmetry which, as suggested by Munk, can probably be attributed to the effect of the earth's rotation.

Mr. Ursell then presented a mathematical paper in which he sought for the conditions under which waves could give rise to currents. Assuming, initially, a steady state in which waves of small amplitude are propagated without change of shape on a flat rotating earth he showed from the equations of motion that there can be no mass transport along the crests and then, by applying the circulation theorem, that there can be no transport in the line of advance of the waves. If, however, we now consider a system of waves (swell) moving into an area of still water the resulting wave motion must be non-rotational since it is generated from rest and therefore the waves must be of the Stokes type, and cannot be Gerstner waves which are rotational. Stokes waves possess mass transport and therefore it would appear that a swell can give rise to a component of current.

Mr. Corkan then described, at length, the work carried out by Dr. Doodson and himself on meteorological or storm surges in the North Sea. The difference between the actual tide at a place and the astronomical or predicted tide adjusted for distortion must be due to the meteorological factors, wind and atmospheric pressure. It is usual to eliminate the effects of barometric pressure by assuming that the hydrostatic law is an adequate approximation. In the theory it is usual to regard the North Sea as a canal with a boundary across the Straits of Dover and open to the ocean at its northern end. Storm effects may then be divided into two classes, internal effects which can be dealt with on theoretical lines and external effects which enter the North Sea from the north and travel southwards like a progressive wave. It is possible to forecast the

incidence of external storm surges at Southend by noting the time they pass some point further north. In practice it is found that the time interval of travel between Dunbar and Southend is about nine hours. These external surges may be due to the effect of the travel of depressions east and north-east to the north of the British Isles. Mr. Corkan went on to show how the data gained in this work can be utilised to determine the values of the eddy viscosity and the damping factor. The free period of the North Sea was estimated to be of the order of 30 hours. Those interested in storm surges will find further details in an article by the speaker which appeared in *The Dock and Harbour Authority*, February 1948. An abridged version of this article has been published in the *Marine Observer* (January 1949).

Other speakers included Sir Geoffrey Taylor, Prof. Sheppard and Mr. Durst.

In his concluding remarks Dr. Doodson regretted that there was insufficient time for an adequate discussion of the broader issues involved owing to the time taken by the opening speakers. This sentiment was shared by most of the meteorologists present.

T. H. KIRK.

FRENCH INSTITUTE, LONDON

A talk on the " Light of the night sky " was given by Prof. Cabannes of the Sorbonne, Paris, at the French Institute in London on Tuesday November 23, 1948. Prof. E. N. da C. Andrade introduced the speaker.

Prof. Cabannes began by illustrating the existence of the light of the night sky by showing lantern slides of photographs taken by the aid of this light alone. After describing the work at the observatory at the Pic du Midi and also the spectrograph used in the experiments, he went on to discuss the nature and origin of the phenomena observed.

The spectrographic plates showed that the night sky radiates energy of a total intensity too great to be explained by starlight alone, and that, in fact, 56 per cent. of the continuous spectrum was to be accounted for.

The theory that this portion may be due to radiations from interplanetary space has been tested by examining the polarization of the incoming light. The slight degree of polarization detected suggests that part may be due to this source, equivalent to an extension of the zodiacal light. Calculations give a possible 15 per cent., leaving 41 per cent. still to be explained.

The light emitted by the stars is dispersed by the particles in its path, which results in an apparent magnification of the size of a star as observed on the earth. This magnification is found to be selective as regards the wavelength of the light, indicating a selective absorption which does not comply with the Rayleigh scattering formula but which can be explained, by the aid of Mie's equations, as being due to absorption by particles of molecular size, not electrons or large particles. Light scattered by molecules in space in this manner is estimated to contribute 10 per cent. to the total continuous spectrum of the night sky.

Researches by Barbier show that the remaining 31 per cent. originates in the earth's atmosphere. Comparisons made between the spectra of the night sky and those of the sun determined the characteristic lines from this source as the green and the red oxygen lines and the sodium line, which indicated the

presence of sodium atoms in the upper atmosphere, also the nitrogen bands having a distinctive sharp boundary. These lines were explained by energy changes taking place between atoms in a metastable state through the agency of a third particle which could be a molecule of the same element.

Examination of the energy of the light of the night sky by Dufay has determined the lines and bands due to these three-particle collisions in the upper atmosphere. He has also shown that a close correlation exists between their intensity and the activity of sunspots.

D. D. CLARK

LETTERS TO THE EDITOR

Barograms from big ships—action of ocean waves and gusty winds

The development by the Instruments Branch of the Meteorological Office of an arrangement whereby an open-scale barograph can be taken to sea in a small ship and give a trace as fine, and almost as reliable, as at a land station is a remarkable achievement. Mr. Bibby's introductory statement of the problem in his account of this development* seems, however, to contain some misconceptions regarding the behaviour of the bigger ships at sea, which should be corrected if we are to avoid false conclusions about the magnitude of the pressure fluctuations in a turbulent atmosphere over the sea from examination of their barograms.

The whaling-factory ship *Balaena*, on which I spent over five months in the Southern Ocean, is a vessel of over 15,000 registered tons. Her behaviour as regards rolling and pitching would therefore approximate more closely to that of a large passenger liner than to an ocean weather ship, though we may presume that the vibration caused by the winches used in dismembering whale carcasses must be far greater than any vibration experienced on a great passenger ship. Yet the *Balaena* barograms show that occasional broadening of the trace was almost entirely due to the rolling and pitching of the ship in heavy sea.

As we read in the newspapers of occasional damage to furniture and fittings and injury to passengers on even the largest and most modern ocean liners in North Atlantic storms in winter, it is fair to assume that on these vessels also the movement of the ships in heavy seas is of more account than mechanical vibration or any possible fluctuations of pressure due to gustiness of the wind. Indeed it is only in the seas accompanying winds between force 4 and force 6 that the larger vessels are likely to give appreciably smoother traces than the smaller craft.

These conclusions may be illustrated by the *Balaena* barograms shown in Figs. 1, 2 and 3, facing p. 52. The instrument was an ordinary open-scale barograph as used at land-stations†, mounted on an eight-times folded soft woollen blanket. This mounting was roughly equivalent to the rubber-pad mounting used in the experiment on board O.W.S. *Weather Observer*, and was used throughout the voyage after early experiments with various suspensions had shown that it was the best that could be contrived with the materials available on board. Winds were measured with a revolving-cup anemometer installation.

*BIBBY, J. R. ; The use of barographs in ships. *Met. Mag., London*, **77**, 1948, p. 176.

†The traces have been photographically reduced in size a little.

It should be explained that where the pack-ice afforded shelter heavy seas did not invariably accompany strong winds, and the effects of each could therefore be studied separately. The conclusion was soon reached that any broadening of the trace could be taken as a certain indicator of moderate to heavy seas. It was probably also affected by the orientation and speed of the vessel with respect to the waves.

The broadest traces—3–3½ mb. broad—were recorded on the outward and homeward voyages when *Balaena* was steaming through the heavy swells of the roaring forties and fifties, actually with winds between Beaufort force 5 and 8.

The trace for February 24–26, 1947 (Fig. 1) includes a period near the ice in 65°S. 113°E. when a SE., force 11, wind was observed, and swell was less severe than in the crossings of the open ocean. Successive observations were as follows:—

Date	Time	Wind	Sea
	G.M.T.		
24.2.47	1200	SE'E. force 7, gusty	Heavy NE. swell
	1800	ESE. force 9	—
25.2.47	0000	SE. force 11	Heavy E. swell
	0600	SE. force 9	Moderate E. swell
	1200	SE'S. force 6	No swell
	1800	SSE. force 5	—
26.2.47	0000	S'E. force 4	No swell

The waves described as swell in these observations were all about 100 m. long, from crest to crest ; heavy swell means waves over 4 m. high, from crest to trough, and moderate swell means waves between 2 and 4 m. high. Swell was not observed in darkness at 1800 G.M.T. It will be noticed that the barograph trace became fine as soon as the swell ceased, although the wind was still force 6 or over. The heading of the vessel varied during the period.

The trace for March 3–5, 1947 (Fig. 2), recorded near the same position, is also interesting. At 1200 G.M.T. on the 3rd the wind was SE'E. force 8, with only a slight swell, less than 2 m. high, and the trace was still quite smooth although the wind had been force 6 or more for over twelve hours. The next observations were as follows :—

Date	Time	Wind	Sea
	G.M.T.		
3.3.47	1800	SE. force 9	No swell or sea observations on account of darkness.
4.3.47	0000	SE. for. 7. gusty	Moderate NE. swell
	0600	SE. force 6, gusty	Moderate NE. swell
	1200	SE. force 5, gusty	M.derate NW. swell
	1800	SE. force 6	—
5.3.47	0000	ESE. force 5	Moderate WNW. swell
	0600	E'S. force 4	Slight WNW. swell

It will be noticed from Fig. 2 that the trace did not begin to broaden until about 2300 G.M.T. on the 3rd, *i.e.* when the wind had already begun to moderate. The broad trace continued until about 0600 G.M.T. on the 5th, when the swell disappeared. During this period the wind was at times only force 4–5. The gustiness referred to in some of these observations was of the type of minor squalliness commonly associated with unstable air. The north-westerly swell

[To face page 52

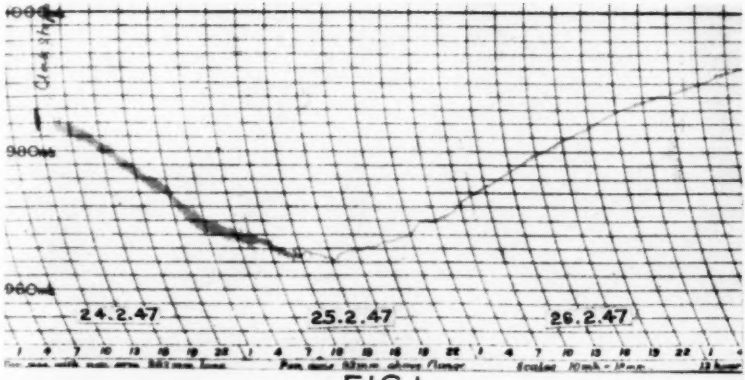


FIG. 1

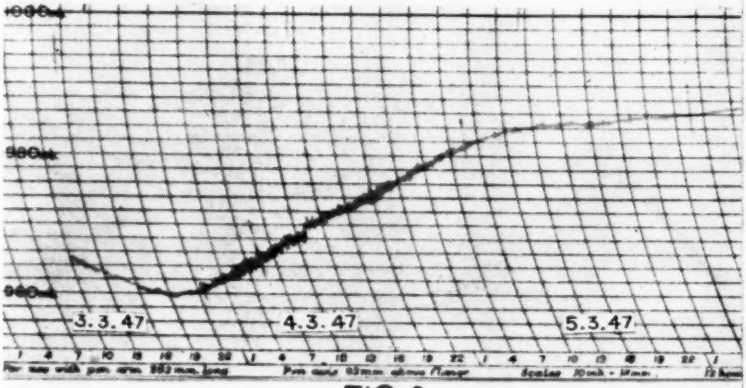


FIG. 2

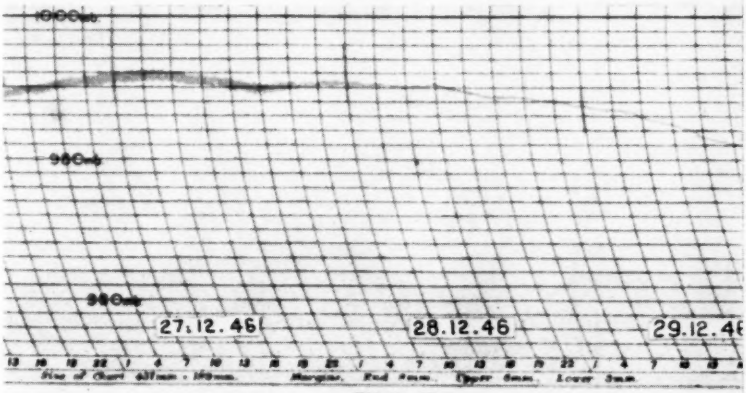
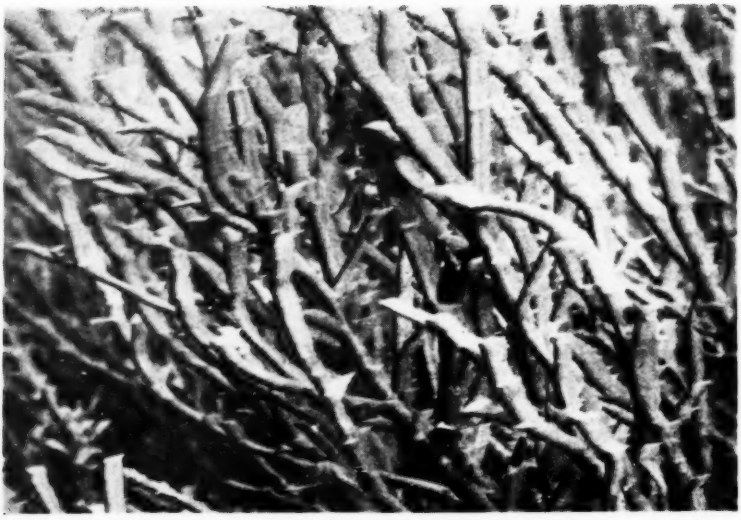


FIG. 3

BAROGRAMS TAKEN ABOARD W/F *Balaena*, 1946–47

(see p. 51)



RIME AT SYERSTON, NOTTINGHAMSHIRE, NOVEMBER 23, 1948

(see p. 54)

reported was a long swell, over 200 m. from crest to crest, and was evidently set up by strong winds elsewhere over the open ocean to the north.

Finally we may examine the trace recorded on December 27–28, 1946, near 58°S. 80°E. (Fig. 3). On the 27th the trace was over 1-mb. broad although the wind was force 1 at most of the observations : there was a moderate, and at one time heavy, northerly swell. The full observations were as followed :—

Date	Time	Wind	Sea
	G.M.T.		
27.12.46	0000	NNW. force 1	—
	0600	N. force 1	Heavy N. swell
	1200	NW. force 1	Moderate NW. swell
	1800	NNE. force 3	Moderate N. swell
28.12.46	0000	NE. force 2	—
	0600	NE. force 3	Slight N. swell
	1200	E. force 3	Slight NE. swell
	1800	E. force 3	No swell

The gradual improvement in fineness of the trace on the 28th clearly corresponded to the diminishing swell.

No doubt a vessel, particularly a large vessel, will set up eddies in the wind stream which are usually an almost stationary feature of the flow pattern. There is no reason to suppose, however, that this will have even as much effect on the barograph as the gusts representing moving eddies which pass over a land station.

It is true, too, that the observer on a big ship (particularly if he is high above the water-line) will be aware of a regular rising and falling of the relative wind as the ship, riding the bigger waves, sways to and fro in the wind stream.

In general, however, gustiness is less noticeable at sea than over the land, and we conclude that it is the movement of the vessel which is chiefly responsible for broadening the barograph traces. There is no evidence in these examples of any appreciable effect due to gustiness.

H. H. LAMB

September 3, 1948

[The first section of my article admittedly contained a good deal of conjecture, and Mr. Lamb's first-hand observations are therefore especially welcome. It would be interesting to know if he came to any conclusion about the exact cause of the movement of the barograph pen ; whether it was mechanical acceleration or pressure oscillations induced by the swell. It should be possible to decide this by carefully noting the phase of the pen oscillation relative to that of the ship. Evidence on this point from ocean weather ships' officers would also be valuable, as indicating whether small ships are affected differently ; and also whether a further improvement in ships' barographs would be obtained by counterbalancing the pen arm.—J. R. BIBBY].

Rime at Leeming on November 23, 1948

There was widespread deposition of rime on trees and shrubs in the vicinity of the R.A.F. Station at Leeming on November 23, 1948. Fig. 1, facing p. 40, and Figs. 2 and 3, facing p. 41, show the deposition on a cobweb and on trees and shrubs.

The close-up, Fig. 3, is the most impressive showing the formation of rime ice only on the windward (south-south-easterly) side of twigs and leaves, and shows the original approximately three-quarters natural size. This is the surface

equivalent of rime accretion on the leading edges of aircraft flying in clouds, and is formed in an identical manner by small supercooled water droplets being disturbed by impact with an obstruction. The ice build-up consisted of small soft white ice pellets loosely joined, and the light south-south-easterly wind was sufficient to shake them off the foliage and give rise to a shallow carpet of "snow". Roads overhung by large trees were made treacherous in this manner. Figs. 1 and 2 were taken at 0930 and Fig. 3 at 1430 on November 23.

Summary of weather conditions from 1900 *November* 22 *to* 1430 *November* 23.—Screen air temperature fell below freezing point at 1900 on the 22nd and remained below freezing with minimum temperature 22°F.; the air became saturated at 2200 and remained saturated; fog (visibility below 1,100 yd.) first formed at 0100 on the 23rd and persisted; and the surface wind was calm until 0400 on the 23rd becoming south-south-easterly 2–4 m.p.h. thereafter.

Weather at 0930 *November* 23.—Fog, sky obscured, visibility 200 yd., wind south-south-easterly 3 m.p.h., temperature 25°F., and relative humidity 100 per cent.

Weather at 1430 *November* 23.—Fog, sky obscured, visibility 80 yd., wind south-south-easterly 2 m.p.h., temperature 28°F., and relative humidity 100 per cent.

B. FOX-HOLMES

Leeming, Yorks, November 23, 1948

Rime at Syerston, Nottinghamshire

The two photographs (facing p. 53) of rime formation at Syerston are thought to be of interest. The formation occurred on the night of November 22 to 23, 1948, which was a period of dense fog with a night minimum temperature of 29°F. and surface wind light south-westerly or calm.

The formation was about an inch in length and on twigs from an eighth to a quarter of an inch in diameter.

F. F. HARRINGTON

Syerston, Notts., November 26, 1948.

NOTES AND NEWS

Meteorological pamphlets presented by Mr. C. E. Britton

Mr. C. E. Britton has followed his gift of old meteorological prints* for the decoration of the conference room at Victory House, by presenting some old and rare meteorological pamphlets to the Meteorological Office Library.

Among the more interesting of these old pamphlets may be mentioned:—

(*a*) A description of the well known destruction by lightning of the church at Widecombe in the Moor, Devonshire, on October 21, 1638. This contemporary account is in a relatively matter-of-fact style for the times and is free from the fantastic embellishments found in others.

(*b*) A pamphlet on the floods in the north of England in November 1771 following three days continuous rain. Among the events described is the washing of peat from Solway Moss over a large agricultural area.

(*c*) An astrological almanac for the years 1648–50 by the well known astronomer William Lilly. Included in this almanac is an account of mock

*see *Met. Mag., London*, **77**, 1948, p. 233.

suns seen in Lancashire on February 28, 1648. The observer of the mock suns in his letter to Lilly said he thought they were due to " naturall causes being but the brightness of the Suns beams, from a cloud reflected on the earth ", but asked, nevertheless, for Lilly's "Astrologicall judgement hereupon " which was duly provided in full measure.

(*d*) An account in Latin of mock suns seen at Wittenberg in Saxony on January 11, 1736. There is no astrology in this pamphlet, by John Wiedler and dedicated to the secretary of the Royal Society, which contains a lengthy dissertation on ancient and modern observations and themes of mock suns. Greater prominence is given to Descartes' and Huyghens' somewhat fantastic theories, which were only correct in that they did attribute the phenomena to refraction, than to Mariotte's theory, which is correctly based on refraction through ice prisms. The pamphlet gives also an account of an aurora seen over Europe as far south as Rome on December 16, 1736.

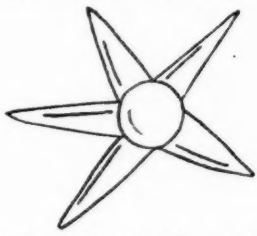
(*e*) Contemporary broadsheets descriptive of the burning of a ship off Gravesend in 1687 after being struck by lightning, the snowstorms of December 23, 1684, and early March 1674, and a newspaper cutting on the Frost Fair on the Thames in December 1813 and January 1814.

Unusual hailstones

The following account of unusual hailstones, sent to us by Mrs. P. O. Bickford of Kapsaret Estate, Eldoret (0°35′N. 35°20′E. 7,000 ft.), may be of interest.

" On Friday August 6 on this Estate, 8 miles from Eldoret on the Kapsaret road, at 5 p.m., there occurred a rather singular fall of hail which I thought might be of interest to you, though it may be quite familiar to you.

The sky became very dark and large hailstones fell, but in the shape of stars similar to those of snow crystals in shape (when seen under the microscope). They nearly all measured 1½ in. in width. They consisted of large ice balls the size of a very large pea with fine radiating arms of ice. Some of these landed on their sides and stuck sideways on in the grass. These soon gave way to rain. Some were of a squarish shape but these were not perfect."



There was a zone of convergence over this area between south-easterly and south-westerly winds on August 6 with the freezing level at 15,000 ft.

W. A. GRINSTED

Nairobi, Kenya, August 31, 1948

[Hailstones of this shape are very rare. A photograph of one which fell in Germany in 1898 is given in " Physik der Atmosphäre " by A. Wegener and K. Wegener (Leipzig, 1935), p. 174 copied from *Met. Z. Braunschweig*, **15**, 1898, p. 41.—Ed. *M.M.*]

REVIEWS

On the thermal structure of the atmosphere over Agra, by R. Ananthakrishnan. Memoirs of the India Meteorological Department, Vol. XXVII, Part IV, 4to, 12 in. × 9¼ in., pp. 61–100, *Illus.*, Delhi, Manager of Publications, 1948. Price: *Rs.* 2 or 3*s.*

Thanks to the comprehensive programmes of upper air soundings carried out by the India Meteorological Department, the characteristics of the atmosphere over Agra are probably better known than those over almost any other place outside Europe and North America. Nevertheless, the new study by R. Ananthakrishnan, presenting monthly mean values based on ten years' records is a welcome addition to our knowledge of the free atmosphere.

The author pays particular attention to the lapse rate and to the occurrence of inversions. As he points out, statistical treatment of the tropopause is difficult because of its complex structure in winter, but the figures given, which are based on the mean lapse rate, will leave out of account the lower branch of many occasions of double tropopause and may be misleading.

In discussing the factors controlling the temperature of the upper troposphere the author rightly emphasises the radiation balance in the dry season and the latent heat released by convection in the monsoon.

J. S. SAWYER

British Thunderstorms. Sixth Report, 1936–37, Vol. 2, Part 3, 8vo, 8½ in. × 5½ in., pp. 97–144, *Illus.*, Huddersfield, Thunderstorm Census Organisation, 1948. Price 5*s.*

This report is a survey in time and space of the thunderstorms over the British Isles for the years 1936 and 1937, set out in the following manner. There is a synopsis of the results in two tables of the number of days with thunder and lightning in England, Wales, Scotland, Ireland and the British Isles for each month from October 1935 to December 1937. There are also descriptive notes on the thundery activity of each month of the years 1936 and 1937 illustrated by quarterly and monthly maps in black and green of the number of days with storms and a report by T. E. Dark on trees struck by lightning. Finally there is a detailed descriptive account of the widespread outbreak of thunderstorms on July 15, 1937, illustrated by a rainfall map of that day and another of hourly isochrones. Included in the volume are reviews of a number of some recent publications on thunderstorms and lightning.

We are greatly indebted to the Thunderstorm Organization for collecting this data in so handy a form. To the reviewer the display of the elemental forces, so prodigally released in a severe thunderstorm, is the most awe-inspiring experience of power and might in the world. We are tempted to ask for greater detail. From the academic and practical points of view something more is needed for the apprehension of a thunderstorm than a record of thunder heard or lightning seen. It is suggested that there should be given, for different places, monthly tables giving dates and times of onset and termination of each storm as well as its severity and direction of motion, the number of the flashes seen, especially those to earth, and remarks on any interesting associated phenomenon, e.g. hail, squalls, lightning damage, fall of temperature, rise of pressure and changes of wind direction. The recording of many of these items in the tables could be simplified by a code of numbers. If space does not permit of this, monthly frequency tables of the different data could be given for each place as well as detailed data for the outstandingly severe storms.

When data extends over a number of years it is always more satisfactory to have the more recent information first. In this connexion it is suggested that the data for the more recent years be published first. It is satisfactory to note, however, that a summary for 1946 has been included as a loose leaflet in this volume.

J. E. BELASCO

A low pressure portable hydrogen generator for pilot balloon observatories. By L. S. Mathur. Scientific Notes of the India Meteorological Department. Vol. IX, No. 114. 8vo. pp. 161–5. *Illus.*, Delhi. Manager of Publications, 1948. Price : *Annas* 0–5–0 or 6*d.*

This paper describes a silicol-caustic-soda-type low-pressure hydrogen generator for use in inflating pilot balloons. The generator is, in general, similar to other generators serving the same purpose. It consists of a generator unit and a scrubber unit for cooling the gas after generation.

Measured quantities of boiling water and caustic soda are first placed in the generator, after which its lid is bolted down. A measured quantity of powdered ferro-silicon is then introduced into the generator through a special fitting in the lid and generation of hydrogen takes place. The gas from the generator is fed into the scrubber where it bubbles through water which cools it and traps any fine alkali spray which may be carried over by the gas. The outlet from the scrubber has a double-sized nozzle, to accommodate balloon necks of various sizes, and a stop cock. Two points of particular interest are :—

(1) The use of boiling water to start with ; when generators of this type are started from cold, there are occasions when the reaction is either very slow or does not start at all.

(2) The method of introduction of the ferro-silicon charge, which can be done without losing any appreciable quantity of gas from the generator.

No safety valve appears to be fitted. The description includes a table of quantities of chemicals required for various sizes of balloons, full instructions for use, and a list of safety precautions. There are three pages of illustrations which make the description easy to follow.

G. E. W. HARTLEY

WEATHER OF DECEMBER 1948

From the 1st to the 15th pressure was generally high on the continent and low out on the Atlantic, and several secondary depressions moved northwards or north-eastwards across the western parts of the British Isles between the 5th and the 10th. After a large anticyclone had developed over France on the 16th, pressure was rather high until the 27th, reaching 1040 mb. locally from the 19th to the 21st. Troughs of low pressure then moved eastwards across the country, and the month ended with pressure below 960 mb. in the west of Ireland.

Mean pressure for the month was above 1030 mb. in the northern part of the Balkans and above 1020 mb. over southern and central Europe and the Mediterranean. It was below 1000 mb. over a large area south-westward of Iceland, and was about 993 mb. in 60°N. 30°W. The mean was more than 10 mb. above normal in the northern part of the Balkans and more than 5 mb. below normal southward of Iceland.

Over the British Isles the weather was unusually mild and unsettled during the first half of the month. Subsequently cold, dry weather prevailed until the 26th in the west and the 28th in eastern districts. Thereafter unsettled conditions were renewed and persisted until the end of the month.

The cold, foggy weather experienced at the end of November continued in some eastern districts until the evening of December 1. Broadly speaking, from the 1st to 15th a complex area of low pressure was situated in the north-east Atlantic, while secondary disturbances formed westward of the Azores and moved rather quickly east and then either north-north-east along the western seaboard of the British Isles or north-east across the country. The air flow over the British Isles was drawn from the neighbourhood of the Azores and temperature was notably high for the time of year. Rain occurred frequently and was heavy locally at times, particularly in the west. Thunderstorms were recorded locally from the 6th to 9th and were rather widespread in the southern half of England on the 13th and 14th. Winds were often strong and gale force was reached at exposed stations on a number of days, particularly in the west. Among the heavier falls of rain in 24 hours during this period were 3·81 in. at Llyn-y-fan Fach, Carmarthen, and 3·74 in. at Trecastle, Brecon, on the 2nd, 2·97 in. at Gruline, Mull, and 2·40 in. at Florencecourt, Co. Fermanagh, on the 5th, and 2·75 in. at Watendlath, Cumberland, on the 11th.

From the 15th to 18th an anticyclone near the Azores and a ridge westward of the British Isles moved north-east, and subsequently high pressure was established on the continent with a ridge extending west over the British Isles. Temperature fell appreciably and there was little or no rainfall. By the 21st pressure was highest in an anticyclone centred near Thorshavn and, during the following days this system moved south-south-east to combine with a high over central and south-east Europe. Over the British Isles weather continued dry and cold, the 26th and 27th being particularly cold in parts of England and south Scotland; for example, at Honiley in Warwickshire, temperature remained continuously below freezing point on these days, while a screen minimum temperature of 15°F. was registered at Bristol on the 26th and one of 17°F. at Mildenhall, Suffolk, on the 27th.

A change to unsettled conditions took place in the west on the 26th and 27th. On the 28th a trough of low pressure, associated with a very deep depression moving north-east across Iceland, moved over the British Isles giving strong winds, local gales and considerable rainfall. On the 30th a secondary depression moving east-south-east over southern districts gave snow from Wales to the Humber and Wash areas amounting to 12 in. at Wirksworth, Derbyshire, and 8 in. at Mansfield, Nottinghamshire, and heavy rain a little further south. On the closing day a depression developed on the Atlantic and moved rapidly eastward, deepening as it moved and by midnight pressure had fallen to the extremely low level of 957 mb. in north-west Ireland and was still falling. Among falls of more than 2 in. of rain were 2·11 in. at Inveraray Castle, Argyll, on the 28th, 2·41 in. at Beulah, Brecon, on the 30th and 2·25 in. at Rhondda Water Works, Glamorgan, on the 31st.

The general character of the weather is shown by the following provisional figures.

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	62	13	+2·0	114	−2	134	23
Scotland	65	14	+2·1	112	−2	103	16
Northern Ireland ..	62	22	+1·5	146	−2	123	22

RAINFALL OF DECEMBER 1948

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	2·20	92	*Glam.*	Cardiff, Penylan ..	4·95	99
Kent	Folkestone, Cherry Gdns.	2·32	72	*Pemb.*	St. Ann's Head ..	4·76	100
,,	Edenbridge, Falconhurst	4·47	135	*Card.*	Aberystwyth	6·16	155
Sussex	Compton, Compton Ho.	5·67	135	*Radnor*	Bir. W. W., Tyrmynydd	12·15	148
,,	Worthing, Beach Ho.Pk.	2·89	96	*Mont.*	Lake Vyrnwy	7·31	105
Hants	Ventnor, Roy. Nat. Hos.	3·86	117	*Mer.* .	Blaenau Festiniog ..	10·15	80
,,	Bournemouth	5·16	133	*Carn.*	Llandudno	4·25	147
,,	Sherborne St. John ..	4·63	141	*Angl.*	Llanerchymedd ..	4·67	106
Herts.	Royston, Therfield Rec.	1·86	80	*I. Man.*	Douglas, Boro' Cem. ..	4·90	99
Bucks.	Slough, Upton	3·17	126	*Wigtown*	Port William, Monreith	4·41	97
Oxford	Oxford, Radcliffe ..	2·70	110	*Dumf.*	Dumfries, Crichton R.I.	6·09	142
N'hant.	Wellingboro', Swanspool	2·77	118	,,	Eskdalemuir Obsy. ..	7·89	113
Essex	Shoeburyness	1·72	93	*Roxb.*	Kelso, Floors	1·88	81
Suffolk	Campsea Ashe, High Ho.	·93	40	*Peebles*	Stobo Castle	5·40	142
,,	Lowestoft Sec. School ..	1·56	67	*Berwick*	Marchmont House ..	2·10	75
,,	Bury St. Ed., Westley H.	1·75	73	*E. Loth.*	North Berwick Res. ..	1·39	65
Norfolk	Sandringham Ho. Gdns.	2·05	81	*Midl'n.*	Edinburgh, Blackf'd. H.	2·20	94
Wilts.	Bishops Cannings ..	3·88	118	*Lanark*	Hamilton W. W., T'nhill	5·32	123
Dorset	Creech Grange.. ..	4·61	105	*Ayr*	Colmonell, Knockdolian	6·11	109
,,	Beaminster, East St. ..	7·41	155	,,	Glen Afton, Ayr San ..	9·29	145
Devon	Teignmouth, Den Gdns.	6·76	160	*Bute*	Rothesay, Ardencraig	7·71	141
,,	Cullompton	5·92	135	*Argyll*	L. Sunart, Glenborrodale	11·01	126
,,	Barnstaple, N. Dev. Ath.	4·38	99	,,	Poltalloch	8·12	127
,,	Okehampton, Uplands	10·80	153	,,	Inveraray Castle ..	10·78	109
Cornwall	Bude School House ..	5·74	132	,,	Islay, Eallabus ..	7·40	125
,,	Penzance, Morrab Gdns.	7·38	130	,,	Tiree	7·44	142
,,	St. Austell, Trevarna ..	7·27	119	*Kinross*	Loch Leven Sluice ..	4·38	111
,,	Scilly, Tresco Abbey ..	5·72	122	*Fife*	Leuchars Airfield ..	2·83	115
Glos.	Cirencester	4·44	125	*Perth*	Loch Dhu	14·16	140
Salop.	Church Stretton ..	3·84	109	,,	Crieff, Strathearn Hyd.	7·21	161
,,	Cheswardine Hall ..	3·67	130	,,	Pitlochry, Fincastle ..	6·84	169
Staffs.	Leek, Wall Grange P.S.	4·00	107	*Angus*	Montrose, Sunnyside ..	3·89	140
Worcs.	Malvern, Free Library	3·87	140	*Aberd.*	Balmoral Castle Gdns...	4·62	137
Warwick	Birmingham, Edgbaston	5·00	186	,,	Dyce, Craibstone ..	3·86	114
Leics.	Thornton Reservoir ..	3·64	136	,,	Fyvie Castle	3·28	96
Lincs.	Boston, Skirbeck ..	2·63	122	*Moray*	Gordon Castle	2·12	79
,,	Skegness, Marine Gdns.	2·99	136	*Nairn*	Nairn, Achareidh ..	1·83	89
Notts.	Mansfield, Carr Bank ..	2·98	103	*Inv's*	Loch Ness, Foyers ..	5·28	119
Ches.	Bidston Observatory ..	2·95	111	,,	Glenquoich	13·36	91
Lancs.	Manchester, Whit. Park	2·99	92	,,	Fort William, Teviot ..	9·73	95
,,	Stonyhurst College ..	2·92	60	,,	Skye, Duntuilm ..	7·98	128
,,	Blackpool	2·74	84	*R. & C.*	Ullapool	4·39	72
Yorks.	Wakefield, Clarence Pk.	2·06	85	,,	Applecross Gardens ..	7·73	120
,,	Hull, Pearson Park ..	2·25	93	,,	Achnashellach	7·05	74
,,	Felixkirk, Mt. St. John	2·43	101	,,	Stornoway Airfield ..	5·00	99
,,	York Museum	2·13	95	*Suth.*	Lairg	4·06	101
,,	Scarborough	1·54	65	,,	Loch More, Achfary ..	7·81	85
,,	Middlesbrough	1·17	60	*Caith.*	Wick Airfield	2·98	97
,,	Baldersdale, Hury Res.	3·50	94	*Shet.*	Lerwick Observatory ..	5·74	120
Nor'd.	Newcastle, Leazes Pk. ..	1·89	80	*Ferm.*	Crom Castle	6·59	159
,,	Bellingham, High Green	3·47	96	*Armagh*	Armagh Observatory ..	4·52	144
,,	Lilburn Tower Gdns. ..	2·65	101	*Down*	Seaforde	6·39	155
Cumb.	Geltsdale	2·89	76	*Antrim*	Aldergrove Airfield ..	4·48	131
,,	Keswick, High Hill ..	8·17	122	,,	Ballymena, Harryville ..	5·69	128
,,	Ravenglass, The Grove	5·45	119	*Lon.*	Garvagh, Moneydig ..	6·27	156
Mon.	Abergavenny Larchfield	8·63	194	,,	Londonderry, Creggan	6·16	141
Glam.	Ystalyfera, Wern House	13·58	162	*Tyrone*	Omagh, Edenfel ..	6·60	156

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, AUGUST 1948

Stations	Pressure		Temperatures						Relative humidity	Mean cloud amount	Precipitation			Bright Sunshine	
			Absolute		Mean values										
	Mean of day M.S.L.	Diff. from normal	Max.	Min.	Max.	Min.	½ Max. and Min.	Diff. from normal	Wet bulb		Total	Diff. from normal	Days	Daily mean	Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hr.	%
London, Kew Observatory	1012·9	−2·0	78	46	68·0	54·3	61·1	−1·1	56·9	77	8·1	2·87	+0·63	12	4·7	32
Gibraltar	1016·0	−0·5	95	62	85·1	68·4	76·7	+0·7	70·3	78	3·1	0·00	—	0	11·3	84
Malta	1015·1	+0·3	96	63	86·4	69·5	77·9	−1·2	72·5	62	0·6	0·00	—	0	12·5	93
St. Helena	1018·9	−1·0	69	53	62·3	54·9	58·6	+1·3	54·7	93	9·7	1·37	−1·29	12	—	—
Lungi, Sierra Leone	1013·7		84	70	80·0	73·2	76·7	—	73·8	93	9·5	47·59	—	27	—	—
Lagos, Nigeria ..	1014·1	+1·1	85	63	81·2	69·1	75·1	−2·8	73·5	88	9·6	1·10	—	12	2·1	17
Kaduna, Nigeria ..	1011·7	—	88	64	31·7	67·6	74·7	+0·5	—	—	—	12·07	−0·25	21	4·0	32
Chileka, Nyasaland	1021·7	0·0	87	51	77·3	55·9	66·6	−0·6	58·3	62	2·3	0·02	−0·06	1	6·2	53
Lusaka, Rhodesia ..	1019·0	+0·5	85	46	78·1	52·1	65·1	−0·4	53·2	55	2·0	0·00	0·00	0	9·2	79
Salisbury, Rhodesia	1021·8	+0·2	81	40	72·5	46·0	59·3	−0·8	49·8	57	1·7	0·00	−0·10	0	8·6	75
Cape Town	1021·5	+1·2	80	40	63·3	48·1	55·7	+0·1	47·8	69	5·5	2·00	−1·37	11	—	—
Germiston, South Africa	1023·6	+0·7	79	35	71·8	44·7	58·3	+3·4	43·3	43	1·1	0·00	−0·25	0	10·3	92
Mauritius																
Calcutta, Alipore Obsy.	999·7	−1·0	92	75	89·4	79·2	84·3	+1·1	80·2	91	8·8	14·82	+1·44	25	3·5	27
Bombay	1003·7	−2·2	90	75	85·6	77·5	81·5	+0·7	76·9	87	8·4	17·03	+2·58	22	2·2	17
Madras	1004·1	−1·4	99	73	94·5	78·7	86·6	+0·6	75·5	70	7·4	3·49	−1·05	10	6·3	50
Colombo, Ceylon ..	1009·2	−0·1	86	73	84·7	77·0	80·9	−0·3	76·0	85	7·4	6·60	+3·36	12	7·3	59
Singapore	1008·6	−0·9	92	72	88·3	76·8	82·5	+1·4	77·8	81	7·0	3·38	−4·57	15	—	—
Hongkong	1004·5	−0·3	92	75	88·5	78·1	83·3	+1·2	78·7	84	—	12·34	−2·06	19	7·2	56
Sydney, N.S.W. ..																
Melbourne	1014·2	−3·8	69	35	60·4	43·9	52·1	+1·1	46·2	64	4·7	1·18	−0·69	12	5·5	51
Adelaide	1016·5	−2·7	73	42	63·0	47·3	55·1	+1·1	49·3	63	5·3	2·57	+0·03	14	5·8	54
Perth, W. Australia	1017·9	−1·0	81	39	66·8	50·1	58·5	+2·5	54·5	70	5·0	3·76	−1·89	12	6·9	63
Coolgardie	1018·9	−0·4	82	39	68·4	45·5	56·9	+3·3	47·7	55	1·8	0·45	−0·54	9	—	—
Brisbane	1018·2	−1·0	80	44	71·6	51·4	61·5	+1·1	54·7	62	3·5	1·35	−0·66	8	8·3	74
Hobart, Tasmania	1008·4	−5·0	67	31	57·4	41·1	49·3	+1·3	43·7	68	6·4	0·77	−1·06	10	5·2	50
Wellington, N.Z. ..	1017·2	+2·1	62	34	54·3	42·3	48·3	+1·0	45·6	81	6·2	2·28	−2·21	11	5·5	52
Suva, Fiji	1013·6	−0·6	85	65	77·9	69·5	73·7	+0·1	69·9	81	8·0	5·86	−2·43	19	3·7	32
Apia, Samoa ..	1011·3	−0·6	87	67	85·2	72·1	78·7	+0·2	75·2	77	5·7	3·03	−0·75	10	8·1	69
Kingston, Jamaica	1013·5	0·0	93	72	91·3	75·3	83·3	+1·8	73·8	80	4·0	1·39	−2·16	5	7·5	59
Grenada, W. Indies	—	—	—	72	—	75·7	—	—	77·7	83	8·0	9·00	−0·33	23	—	—
Toronto	1016·1	+0·7	101	52	80·9	60·8	70·9	+3·7	60·4	78	4·7	0·89	−1·90	6	8·5	61
Winnipeg	1013·7	+0·5	91	42	79·6	55·8	67·7	+3·9	56·3	91	5·1	0·94	−1·22	7	8·2	57
St. John, N.B. ..	1013·9	−1·4	87	49	71·7	54·3	63·0	+2·4	58·1	90	6·2	1·60	−2·26	10	7·4	53
Victoria, B.C.	1016·1	−0·8	72	45	66·4	51·6	59·0	−0·7	52·8	93	6·8	2·58	+1·94	14	6·9	48